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(54) A RETRO-REFLECTING ASSEMBLY

(71) I, LUDWIG EIGENMANN, of Swiss Nationality of Vacallo, Canton Tessin, Switzerland, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be described in and by the following statement:—

This invention is concerned with the art of retro-reflectors for providing night-time visibility to traffic markings, more particularly but not exclusively to markings laid or formed on road surfaces, such as traffic dividing lines, as well as other either vertically or horizontally located signs and markings.

More particularly, this invention is concerned with retro-reflecting assemblies comprising a transparent main sphere, such as a glass sphere having an uncoated first surface portion positioned for light impingement, and a plurality of retro-reflective means on said sphere at least at a second surface portion opposite to said first uncoated portion, for reflecting light rays which have passed through and been refracted within said sphere, so that the impinging light will be reflected outside the sphere along a path essentially coinciding with that of its impingement on said uncoated portion.

This art is a well known and well worked one, and a wide patent literature is available thereon. A particular type of such retro-reflecting assembly comprises light reflective means which causes the assembly to behave catoptrically. Assemblies of such a nature are shown for example in Figs. 10 and 11 of the United Kingdom Patent Specification No. 1,343,196 of the same applicant. Such assemblies comprise a plurality of part-spherical convex reflective surfaces opening in a direction away from said main transparent sphere and having a reflective coating. Such assemblies are different in function from those in which the main sphere is at least partially coated with a monolayer of further focusing and reflecting transparent spherical beads of diameter greatly less than that of the said main sphere, which assemblies behave dioptrically. The catoptrically behaving assemblies have been proved to be more efficient optically than the dioptrical ones, but the general efficiency of both types of assembly is undesirably poor when measured in terms of optical response to impinging light, that is to say the ratio of retro-reflected light to incident light.

It is the object of this invention to provide a catoptrically behaving retro-reflective assembly of high optical efficiency.

According to the present invention, a retro-reflecting assembly comprises a transparent sphere whose surface has an uncoated light receptive first portion exposed to incident light beams, and retro-reflective means adjacent to a further portion of the surface of said sphere opposite said first portion, said retro-reflective means being transparent solid bodies bounded by three plane side faces meeting at right angles to each other at an apex, and by a base opposed to said apex, said base being juxtaposed on said further portion of the spherical surface of said transparent sphere. In a preferred construction, the solid bodies are arranged so that their axis passing through the apex and normal to the plane containing the corners of the base passes substantially through the center of the sphere. The side faces may be coated with an inwardly reflective coating.

The solid bodies have been found to be capable of multiple internal reflection such that when a beam of light is passed into the solid body through its base it is totally internally reflected and emerges in a direction parallel to the incident beam.

In such an assembly almost all of the impinging light is reflected in directions very nearly or precisely parallel to that of impingement and retro-reflecting effect of astonishingly highly optical efficiency is obtained.

The provision of such solid bodies can be obtained by a number of procedures, including for example machining and die-forming. Preferably, in view of the obvious necessity to have small dimensions, such solid bodies are formed by causing cubic crystals to grow on the surface of a glass sphere. It is known that such crystals grow

upon development of their apices and therefore, when grown on a surface, they will form an equilateral triangular base, and three other faces all at 90 degrees to each other and meeting at the apex. Compounds exist which crystallize in cubic form and provide transparent crystals of suitable refractive index, and which can be made use of. For example, organic compounds include calcium oxalate and inorganic compounds include spinel (magnesium meta-aluminate $MgAl_2O_4$).

These and other features and advantages of the invention will be apparent from the following description, with reference to the accompanying drawing, wherein:

Fig. 1 corresponds to Fig. 11 of the above referred United Kingdom Patent Specification No. 1,343,196, which is indicative of the prior art assembly most pertinent to the present invention;

Fig. 2 is a fragmentary view of the prior art assembly of Fig. 1, viewed in the direction and from a part-spherical sector indicated by the line II—II in Fig. 1, the latter being an enlarged fragmentary sectional view taken in the plane indicated at line I—I in Fig. 2;

Figs. 3 and 4 are diagrammatic perspective views respectively of a cube and of two tetrahedra assumed to be cut off said cube;

Fig. 5 is a fragmentary cross-sectional view, to a greatly enlarged scale, of a retro-reflecting assembly according to the invention, taken in the plane indicated at V—V in

Fig. 6, which is a fragmentary view of the assembly of Fig. 5, sectioned along and viewed from a part-spherical sector indicated by arrows VI—VI in Fig. 5.

Referring firstly to the prior art assembly shown in Figs. 1 and 2, such device includes a main sphere 20, such as a glass bead, having a coating 326, of a transparent composition, in which are formed a plurality of closely spaced part-spherical recesses provided with a reflective coating 222. Each recess forms an inwardly convex reflective surface having its center at P_0 (the center of the bead which has acted as a die to form the recess in a composition 326). R_1 and R_{11} indicate light beams which are retro-reflected by the assembly, assuming that its components (sphere 20 and the transparent composition) have the most suitable refractive indices. It is evident that a small part only of the light beam, impinging on the exposed portion (not shown) of the assembly, can be retro-reflected by the convex reflective surface of the coating 222.

It has been found that such retro-reflection can be increased by a further mutliple reflection, such as is indicated by light beams R_{11} and R_{11}^1, and more particularly because a beam such as R_{11}, reflected by a first convex portion of said reflective surface of coating 222 having as its tangent a plane such as indicated at T—T, and further reflected by another convex portion having as its tangent the plane indicated at T^1—T^1, can be retro-reflected as indicated at R_{11}^1. This complementary reflection (it has been detected by very careful experimentation) is very small in amount because the areas at which the phenomenon may occur are very small in size compared with the total area of the convex reflecting surfaces, as indicated to a very exaggerated extent by the hatched areas in Fig. 2. It is evident that an assembly which provides such multiple reflective areas will be optically efficient as a function of the relative size of such areas, as a proportion of the entire reflective surface of the convex areas.

Figs. 3 and 4 have been entered in this specification for better definition and understanding of the particular solid bodies characteristic of the invention. Fig. 3 illustrates a cube having eight apexes A, B, ... F, G, H. Assuming that such cube is cut by parallel slanting planes passing respectively through apices B, D, E and apices F, G, H, two tetrahedra are obtained, their apices formed by three plane surfaces which are all at right angles to each other being apex A and apex G respectively. The octahedron B, C, D, E, F, H is the remaining part of the cube from which the said two tetrahedra have been cut off.

Figs. 5 and 6 show an assembly according to the invention. On the spherical surface of a sphere 20, having a suitable refractive index (according to known art) there are provided a plurality of closely spaced tetrahedra 26. These tetrahedra are formed on or grown as crystals on said spherical surface. The thus coated article can be provided with an inwardly reflective further coating 22, if desired or expedient.

Each individual tetrahedron 26 has its base (the equilateral triangles B—E—D and C—F—H) juxtaposed to the spherical surface of the sphere 20, and the light beams to be retro-reflected pass through said bases. If the tetrahedra are uniformly and closely arranged, the sum of the areas of said bases represents a large proportion of said spherical surface, up to its entirety when the production of the article has been optimized. Each light beam which enters such tetrahedra at an angle "alpha" (relatively to the axis 0 of the tetrahedron, that is the straight line passing through the center of the sphere 20 and the apex of the tetrahedron) less than 45 degrees and preferably less than 35 degrees, will be perfectly retro-reflected, as indicated by beams R, R^1.

Further, when the substance with which the tetrahedra 26 are formed has a refractive index of 1.41, the phenomenon of total in-

ternal reflection occurs, that is said tetrahedra retro-reflect even if no reflective coating 22 has been provided, for light beams nearly parallel to axis 0. For higher refractive indices, this phenomenon occurs for beams entering the tetrahedra at a greater angle "alpha". For example, total internal reflection occurs with angle "alpha" not greater than 30 degrees, when the refractive index is approximately 1.5. It is evident that this feature is of paramount importance because it permits the spheres 20 to be made of economical, widely available, wear- and weather-resistant windowpane glass composition, and to have only a small difference between the respective refractory indices of the glass sphere and of the tetrahedra.

Each individual tetrahedron behaves as a catoptrical system having its focus at infinity (the focus of the known catoptrical system of Fig. 1 is at P_v). The refractivity parameters for the main sphere 20 are not critical, because the reflective ability of the tetrahedra is practically independent of the primary refraction caused by the sphere, each individual tetrahedron 26 being capable of reflecting and retro-reflecting each light beam which passes through the sphere tetrahedron interface.

It is evident that a nearly perfect arrangement and uniformity such as is illustrated in Fig. 6 is theoretical. It is however evident that, when an arrangement comparable with that of prior art devices, such as assemblies consisting of a main sphere coated by a monolayer of reflective beads secured thereabout, has been provided, the optical efficiency will be surprisingly improved — inter alia — by the great improvement of the proportion of the sum of the areas through which light can enter the tetrahedra and be retro-reflected therefrom.

It is to be noted that the term "tetrahedron" used herein relation to Figs. 5 and 6 defines a body having three plane faces meeting at the apex, and a base opposite the apex, and that the base surface need not be plane and would most conveniently be part-spherical to conform to the surface of the sphere.

WHAT I CLAIM IS:—

1. A retro-reflecting assembly comprising a transparent sphere whose surface has an uncoated light receptive first portion exposed to incident light beams, and retro-reflective means adjacent to a further portion of the surface of said sphere opposite said first portion, said retro-reflective means being transparent solid bodies bounded by three plane side faces meeting at right angles to each other at an apex, and by a base opposed to said apex, said base being juxtaposed on said further portion of the spherical surface of said transparent sphere.

2. A retro-reflecting assembly, as claimed in claim 1, wherein the solid bodies are arranged so that their axis passing through the apex and normal to the plane containing the corners of the base passes substantially through the center of the sphere.

3. A retro-reflecting assembly, as claimed in either of claims 1 and 2, wherein said side faces are coated with an inwardly reflective coating.

4. A retro-reflecting assembly, as claimed in any one of the preceding claims, wherein the solid bodies are made of a transparent substance having a refractive index of substantially 1.5.

5. A retro-reflective assembly, as claimed in any one of the preceding claims, wherein said transparent sphere is made of glass having a refractive index of at least 1.5.

6. A retro-reflective assembly, as claimed in any one of claims 1 to 5, wherein said retro-reflective means are formed on the surface of said sphere.

7. A retro-reflective assembly, as claimed in any one of claims 1 to 5, wherein said retro-reflective means consist of crystals of a transparent substance which crystallizes in cubic form, said crystals being grown on the surface of said sphere.

8. A retro-reflective assembly as substantially as described herein with reference to Figs. 3 to 6 of the accompanying drawing.

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1426230 COMPLETE SPECIFICATION

1 SHEET This drawing is a reproduction of the Original on a reduced scale

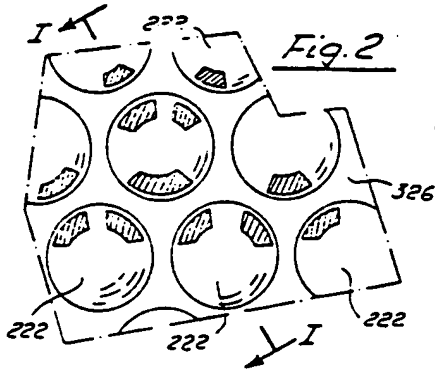

Fig. 2

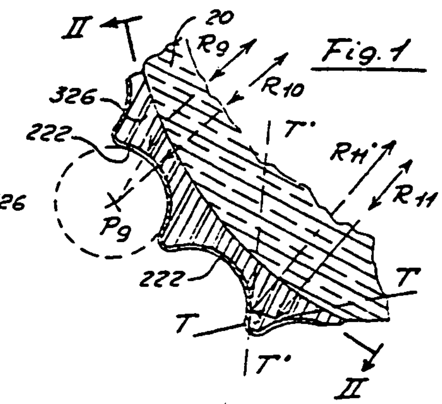

Fig. 1

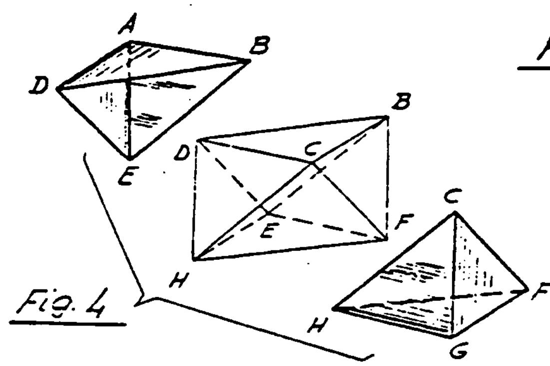

Fig. 4

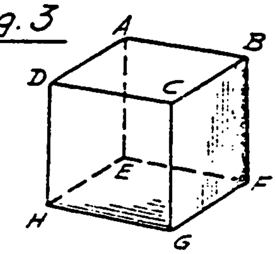

Fig. 3

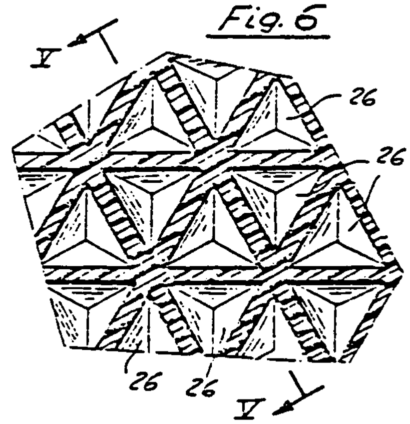

Fig. 6

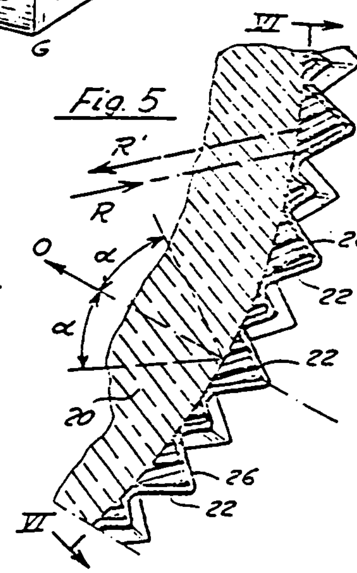

Fig. 5